Application of Gliders for Near-Real Time METOC Data Collection Capability for Battlespace Characterization

Charles Trees
NATO Undersea Research Centre
Viale San Bartolomeo 400, 19126 La Spezia, Italy
phone: (+39) 0187 527 332 fax: (+39) 0187 527 354 email: trees@nurc.nato.int

Award Number: N0001408AF00002

LONG-TERM GOALS

The goal of the program is to substantially improve the uncertainty associated with vicarious calibration and characterization (VC^2) of ocean color satellite sensors by combining hyperspectral apparent optical properties (AOP) and hyperspectral inherent optical properties (IOP) measurements in oligotrophic and coastal areas, with state of the art radiative transfer modeling. A modified Satlantic HyperPRO II hyperspectral radiometer is being used as a portable calibration quality instrument of radiometric uncertainty comparable to that demonstrated for Marine Optical BuoY (MOBY) instruments off Hawaii. By combining these numerous observational platforms, especially gliders that have been outfitted with physical and optical sensors, an efficient and integrated method for real time METOC data collection with Tactical Decision Aid evaluations can be developed.

OBJECTIVES

We propose to design and test an efficient, integrated method for the collection of physical and bio-optical (METOC) data in littoral zones to support military operations. This will include an array of sensors that will operate cooperatively to provide improved and specific data collection capability for local air and sea conditions. The observational platforms will include gliders, moorings, drifters, gliders, ships, aircraft and satellites. The plan is to have two Calibration/Validation cruises in the Ligurian Sea on the *NR/V Alliance* to collect a comprehensive suite of bio-optical and physical data that can be used to improve our understanding of the physical and optical dynamics of a Mediterranean littoral zone, as well as provide initial parameterization and testing of METOC forecasting models. This data will be used to refine our existing geospatial information services and distributed processing system in order to integrate data acquisition facilities, low level processing resources, modeling capabilities, automated decision making and geospatial information managing and dissemination into a common framework. This work will be in close collaboration with Dr. Schofield's efforts on real-time visualization and command/control capabilities for their fleet of coastal gliders. This will be a combined research effort by both US and European investigators. Specific objectives are:

1. To collect *in situ* physical and optical data from a variety of observational platforms that can be used for validating hyperspectral and multi-spectral radiometric data and derived products in the littoral zone, as well as for the adjacent oligotrophic oceanic areas. This would include two cruises: one in the spring, during bloom and elevated river drainage conditions and the other in the fall under more oligotrophic and drier conditions.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Application Of Gliders For Near-Real Time METOC Data Collection Capability For Battlespace Characterization	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NATO Undersea Research Centre,Viale San Bartolomeo 400, 19126 La Spezia, Italy,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **, ,**	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The goal of the program is to substantially improve the uncertainty associated with vicarious calibration and characterization (VC2) of ocean color satellite sensors by combining hyperspectral apparent optical properties (AOP) and hyperspectral inherent optical properties (IOP) measurements in oligotrophic and coastal areas, with state of the art radiative transfer modeling. A modified Satlantic HyperPRO II hyperspectral radiometer is being used as a portable calibration quality instrument of radiometric uncertainty comparable to that demonstrated for Marine Optical BuoY (MOBY) instruments off Hawaii. By combining these numerous observational platforms, especially gliders that have been outfitted with physical and optical sensors, an efficient and integrated method for real time METOC data collection with Tactical Decision Aid evaluations can be developed.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

2. To improve the capabilities of our AUV's and glider(s) by installing bio-optical sensors in these vehicles. This would enable collection of regional sub surface bio-optical and physical data in the littoral zone at more frequent temporal periods (once a month) to describe seasonal and storm induced variability.

3. To provide *in situ* measurements, modeling results and remote sensing observations in real time to cruise participants with the existing broadband communications link between NURC and the *NR/V Alliance*, as well as access by Web-based users on an open source, open architecture geospatial web server (GEOS-II). This will allow for adaptive sampling by the cruise participants during the field trials.

4. To determine uncertainty budgets for *in situ* measurements, modeling results and remotely sensed observations that can be used to evaluate derived products for the littoral zone and provide reliability indices for tactical decisions aids developed using these products and models.

APPROACH

We propose to purchase and integrate optical sensors in a NURC'S Blue Fin Spray glider and the REMUS AUV. These will include backscattering sensors, AUVB sensors and 4-channel downwelling irradiance sensors. There are plans to purchase several shallow water Slocum Coastal gliders in the near future (end 2008) and these will also be instrumented as funds permit. Between the Cal/Val cruises listed below, these gliders will be deployed on a regular basis to provide spatial and seasonal variability of these physical and bio-optical properties, as well as testing the development of real-time METOC data collection and visualization capabilities.

Field Plan --- There are two Cal/Val cruises being planned for the littoral zone of the Ligurian Sea on NURC's R/V Alliance. These two cruises of 14 days in duration and will sample two seasonal extremes in the Ligurian Sea, spring (Mar 09) and fall (Oct 08). NURC will provide for this project the *NR/V Alliance* at the operating cost of ~4,301 Euros day^{-1}, which is the cost only for consumables, such as fuel oil and food. Support for these two cruises will come from several other agencies (ONR, NASA, ESA) and projects.

Below is list of PI's for the LSCV 08 to include instruments/measurements.

Dr. Oscar Schofield, Rutgers University (Slocum gliders)
Dr. Josh Kohut, Rutgers University (Slocum gliders)
Dr. Scott Glenn, Rutgers University (Slocum gliders)
Dr. Mike Twardowski, WET Labs, Inc., (MASCOT and DOLPHIN towed vehicle
Dr. Matt Slivkoff, WET Labs, Inc., USA (DALEC, above water radiometer)
Dr. Ken Voss, University of Miami (NuRADS)
Dr. Kevin Mahoney, NAVOCEANO (Glider and fluor/scattering meters)
Mr. Marc Torres, NAVOCEANO (Slocum gliders, AUVB and ECO Triplet)
Dr. Deric Gray, NRL/Stennis (Multispectral VSF and LISST Scattering)
Mr. Paul Lyon, NRL/Stennis (Above-water reflectances and Micro-TOPs)
Mr. Scott McLean, Satlantic, Inc.(HyperPRO radiometer & radiance camera)
Dr. Ronnie Van Dommelen, Satlantic, Inc.(Radiance camera profiler & sky imager)
Mr. Edouard Leymarie, LOV, FRA (Radiance camera (near surface floating)
Mr. Alexandre Thirouard LOV, FRA (VSF (PolVSM, geniometer; 660 nm)

Dr. Giuseppe Zibordi, JRC, ITA (Multichannel radiometer**)**
Dr. Jean-Francois Berthon, JRC, ITA (Absorption and scattering meters)
Ms. Elisabeth Canuti, JRC, ITA (TSM, CDOM and HPLC sampling)
Dr. Eugeny Shibanow, JRC, UKR (Volume Scattering Meter, VSF)
Dr. Takafumi Hirata, PML, GRB (Flow cytometry & Coulter counter)
Dr Susanne Craig, Dalhousie Un., CAN (Optical modeling and particulate absorption)
Dr. Marlon Lewis, Dalhousie Un., CAN (Modeling)

About one month before the LSCV-08 sea trial (21 Sep to 10 Oct 08) we will deploy three gliders (2-Rutgers University and 1-NAVOCEANO) with bio-optically sensors to sample coastal regions and offshore gyre areas of the Ligurian Sea (see Figure 1). The goal of this glider effort prior to the cruise is to provide information at synoptic scales of the spatial variability of physical and bio-optical properties at sub-basin scales. For the first 2 weeks (23 Sep – 3 Oct) ***Glider 1*** [CTD; 4-channel downwelling irradiance sensor (412, 442, 491 and 664 nm); ECO Triplet 3-Wavelength Backscattering Meter at 117°, b_b(470 nm), b_b(532 nm) and b_b(660 nm)] and ***Glider 2*** [CTD; AUVB Total Scattering (*b*) and Attenuation (*c*) Meter, diver visibility, *c*(532 nm) and *b*(532 nm); ECO Triplet Backscattering and Fluorescence Meter, b_b(880 nm), chlorophyll fluorescence (Ex/Em = 470/695 nm) and CDOM (Ex/Em = 370/460 nm) fluorescence; ECO Triplet 3-Wavelength Backscattering Meter at 117°, b_b(470 nm), b_b(532 nm) and b_b(660 nm)] will carry out transects that sample some of the proposed bio-optical stations to be occupied during the LSCV-08 sea trials. The white boxes and one green box represent no pass-areas by the Italian Navy, because they are shooting/torpedo firing and submarines exercise areas. The trajectory of the third glider [***Glider 3*** -- CTD; AUVB Total Scattering (*b*) and Attenuation (*c*) Meter, diver visibility, *c*(532 nm) and *b*(532 nm); ECO Triplet 3-Wavelength Backscattering Meter at 117°, b_b(470 nm), b_b(532 nm) and b_b(660 nm)] is selected to minimize errors resulting from optimally interpolating data gathered by the three gliders into a predefined grid. Optimal interpolation is based on an anisotropic covariance function computed from satellite imagery. ***Gliders 2*** and ***3*** then will follow similar paths with one being directed by adaptive sampling and the other following pre-programmed transect. ***Gliders 2*** and ***3*** will undulate to 50 m depths as there is a potential for the AUVB optical sensors to leak at deeper depths. ***Glider 1*** has an AUVB optical sensor, but this one has performed well

Figure 1. Tentative glider mission plans (19 Sep to 10 Oct 08) for three gliders based.

DATE	Time	Station	Lat	Long	Location	Distance
15 Oct 08	6:00 AM	Dprt La Spezia				
	10:00AM	Arr Sta 1	43.5°N	9.5°E	Clear water offshore	39 nm
	7:00 PM	Dprt Sta 1				
16 Oct 08	9:00 AM	Arr Sta 2	43.4°N	7.9°E	Boussole Mooring	70 nm
17 Oct 08	9:00 AM	Sta 3	43.4°N	7.9°E	Boussole Mooring	
	7:00 PM	Dprt Sta 3				
18 Oct 08	9:00 AM	Arr Sta 4	42.8°N	6.0°E	Off Toulon	89 nm
	7:00 PM	Dprt Sta 4				
19 Oct 08	9:00 AM	Arr Sta 5	43.2°N	4.7°E	Off Port Saint Louis du Rhone	63 nm
	7:00 PM	Dprt Sta 5				
20 Oct 08	9:00 AM	Arr Sta 6	43.2°N	6.9°E	Off Saint Tropez	120 nm
	7:00 PM	Dprt Sta 6				
21 Oct 08	9:00 AM	Arr Sta 7	44.2°N	9.0°E	Off Genova	110 nm
	7:00 PM	Dprt Sta 7				
22 Oct 08	9:00 AM	Arr Sta 8	43.2°N	8.9°E	Clear water offshore	62 nm
	7:00 PM	Dprt Sta 8				
23 Oct 08	9:00 AM	Arr Sta 9	43.9°N	9.9°E	Off Massa	61 nm
	7:00 PM	Dprt Sta 9				
24 Oct 08	9:00 AM	Arr Sta 10	43.7°N	10.1°E	Off Pisa	18 nm
	7:00 PM	Dprt Sta 10				
25 Oct 08	9:00 AM	Arr Sta 11	43.5°N	10.2°E	Off Livorno	8 nm
	7:00 PM	Dprt Sta 11				
26 Oct 08	9:00 AM	Arr Sta 12	42.8°N	10.5°E	Off Follonica	45 nm
	7:00 PM	Dprt Sta 12				
27 Oct 08	9:00 AM	Arr Sta 13	43.5°N	9.5°E	Clear water offshore	60 nm
	7:00 PM	Dprt Sta 13				
28 Oct 08	9:00 AM	Arr Sta 14	42.8°N	6.0°E	Off La Spezia	36 nm
	3:00 PM	Dprt Sta 14				

Table 1. Tentative station locations with dates and distance between stations.

at depths of 100 m and therefore will undulate/glide to that depth. ***Glider 1*** is also equipped with a 4-channel downwelling irradiance sensor.

The mission time for ***Glider 1*** is around 20 days (1 knot speed) and should have enough time to transit to Sta 2 and 3, which is near the Boussole mooring. The glider paths have been selected to take advantage of the prevailing current, Ligurian-Provencal, that forms a loop current in the central portion of the Ligurian Sea. For ***Gliders 2*** and ***3*** the mission should take around 14 days to reach the area off Livorno. For the remaining 7 days these two gliders will be used to map out the coastal bio-optical

properties. The mission of the ***Glider 3*** will be re-computed adaptively every 4 days on the basis of the SST or optical variations observed from ocean color satellite images (MODIS and MERIS).

Operational Schedule during the Cruise --- The Ligurian Sea Cal/Val Sea Trial (LSCV-08) is scheduled from 15-28 October 2008 on NURC's *NRV Alliance*, a 100m research vessel that holds up to 24 scientific personnel. This will be the largest international effort (USA, FRA, ITA, CAN, GBR, UKR and JAP) for calibration and validation of ocean color satellite data that has been planned to date. A tentative list of station position, date and general location is shown in Table 1 for this 14 day sea trial. These station positions can and will be changed as satellite ocean color data is received, so that those areas with the largest bio-optical gradient are extensively sampled. Both clear and coastal areas will be sampled to include two days around the Boussole mooring, south of Nice, and one day in the more eutrophic waters of the Gulf of Lyons (Figures 2 and 3; Stations 2-3 and 5, respectively).

Figure 2. Station locations on a Google Earth projection.

In preparation of the sea trial, the three gliders will be picked up off Livorno (10 Oct) for battery refurbishment and then deployed from the *NR/V Alliance* at the various bio-optical stations during the sea trial. The idea is to release these gliders from the ship as it comes on station in the morning (~7:00 am). All three gliders will transit towards the coast measuring bio-optical properties (Fig. 4; ***Glider 1*** in the center with ***Gliders 2*** and ***3*** on either side). ***Glider 1*** is the deeper profiling glider (100 m), where as the other two will sample down to 50 m. They will then return to the vessel around mid-afternoon and be commanded to provide continuous profiles about 1.0km away from the central location of the bio-optical station (one on each side; ***Glider 2*** and ***3***) and one inshore (***Glider 1***; Fig. 4). The DOLPHIN, towed undulating bio-optical vehicle, will then be deployed to document intra- and inter-pixel IOP variability in a 'bow-tie' transect with two gliders sampling in the middle of each 'bow-tie' loop. After the DOLPHIN survey (3-4 hrs), the gliders will be retrieved for the next station the following morning. Plans are to sample off the Boussole mooring for 2 days and then transit westward to the Gulf of Lyons off France. This coastal area always has elevated optical signals throughout the year and will provide data in an elevated chlorophyll region for measurement comparisons and modeling efforts. We will then transit eastward towards Genova, sampling a variety of coastal areas and ending up south off La Spezia for the end of the cruise (see Figs. 2 and 3).

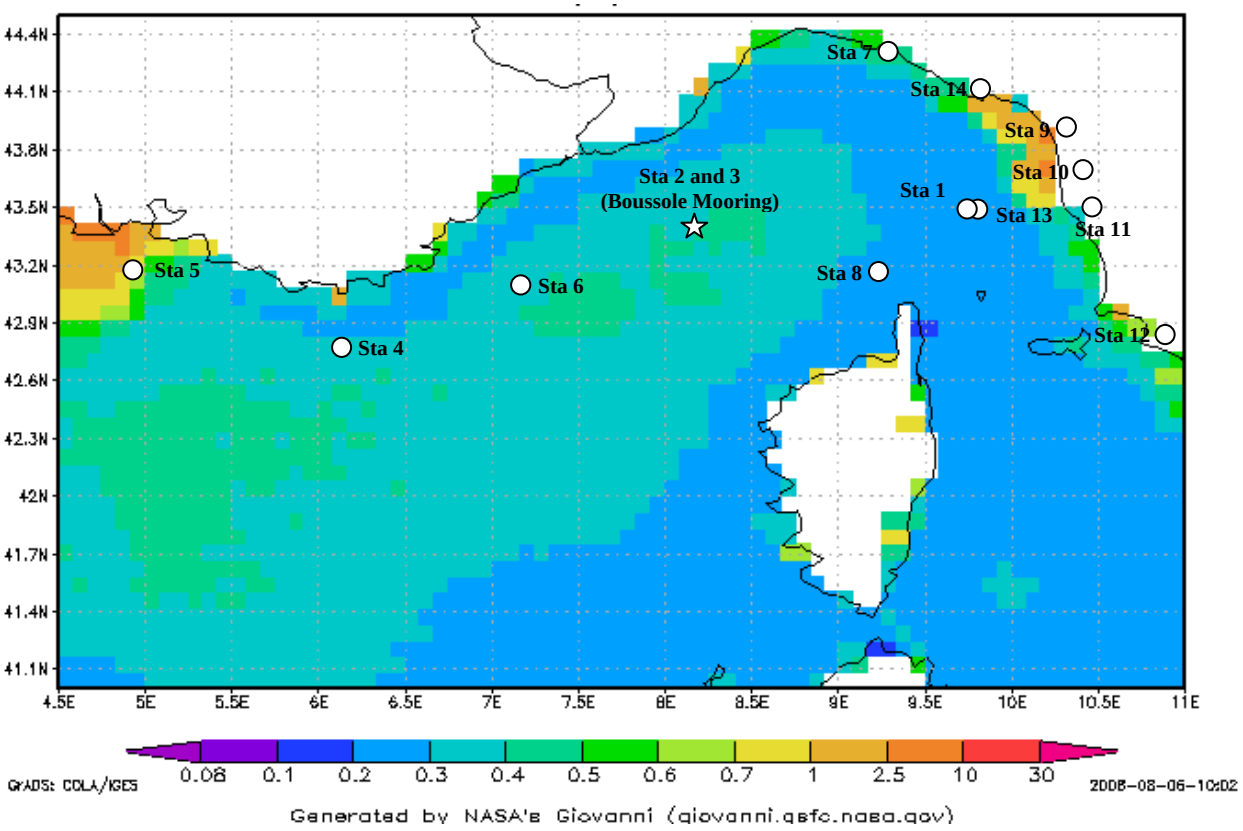

Figure3. Station positions (Oct-Nov 97-07) SeaWiFS mean chlorophyll image.

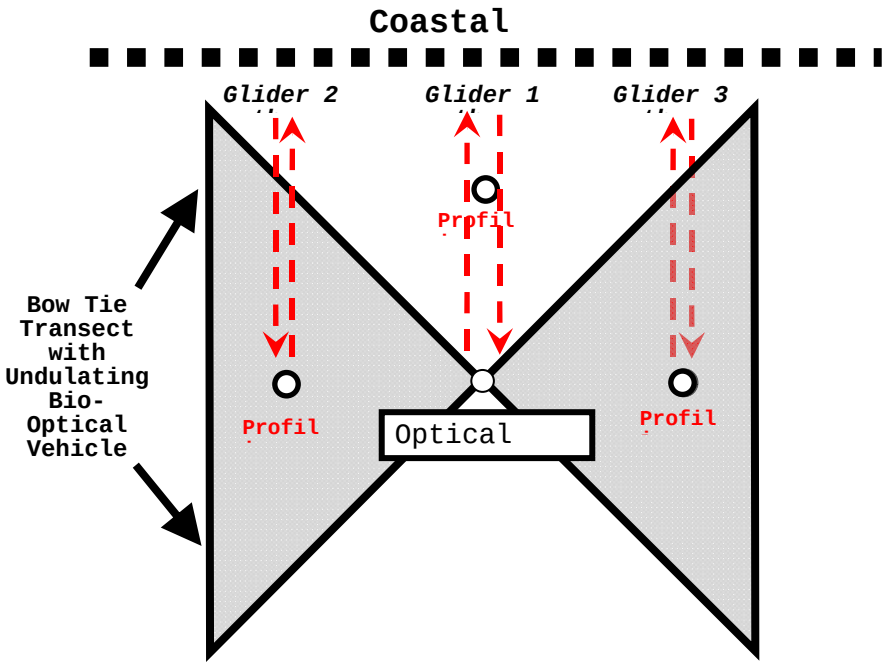

Figure 4. On station glider and towed undulating vehicle sampling plan to determine inter- and intra-pixel bio-optical variability.

Blue water/oceanic stations will also be occupied to complement the coastal ones.

This is undoubtedly the largest US/International calibration and validation effort planned to date. By combining a variety of resources and full set of highly calibrated IOPs and AOPs measurements, a data suite will be obtained at known and low uncertainties for future modeling and remote sensing research.

Additionally, there are 3 different radiance camera systems and 3 different VSF instruments that are going to deployed and inter-compared. This comparison will assist in an evaluation of instrument calibration and optical design. There will also be 4 highly calibrated hyperspectral radiometers deployed during the cruise using new SORTIE measurement protocols. Besides MOBY, these radiometers are unique in that they have had NIST stray correction evaluations performed and integrated into the radiometric processing scheme.

Aircraft Overflight --- During the latter part of the cruise a hyperspectral aircraft sensor will be flown over the ship making radiometric measurements of the water-leaving radiances. These data can be calibrated against the above-water shipboard measurements being performed by NRL-SSC, as well as the water-leaving radiances measured by the three HyperPRO II profiling radiometers. This aircraft data will assist in documenting the intra- inter-pixel variability in these highly dynamic coastal areas. The lead for this effort is Dr. Elena Mauri, (Istituto Nazionale di Oceanografia e Geofisica Sperimentale, OGS-Trieste). The aircraft is 23 Sundowner with an effective operational time of 3hrs staying within stay within 10 miles of the coast for safety purposes. The hypersepctral imaging system is a AISA Eagle (SPECIM, Finland), 400-970nm, that has 100 channels (400-750nm) at 3nm resolution. The pixel size will be between 1.1 to 1.5m depending upon the altitude of the aircraft (1,500 and 2,000m, respectively). The plan is to fly the AISA Eagle during the latter part of the cruise (22-24 Oct) when the bio-optical stations will be off the coast of Italy, between La Spezia and Livorno (see Figures 2 and 3, Stations 8, 9 and 10).

WORK COMPLETED

Two bio-optical instruments (4-channel irradiance sensor and WET Labs ECO Triplet scattering meter) were purchased for installation in NURC gliders and AUVs. In addition, the Oct 08 LSCV08 cruise has been scheduled with all the PIs listed above planning to participate or at least send representatives. Three gliders were launched in Sep 08 and currently one is still operating collecting bio-optical data across the entire Ligurian Sea. Two of them had problems with water leakage and have been retrieved a serviced for later deployment.

RESULTS

The glider data is currently displayed on Rutgers University KOOL room. The *in situ* bio-optical data is not available as the cruise does not start until 15 Oct 08.

IMPACT/APPLICATIONS

Littoral zones are highly dynamic areas in which conditions are spatially variable and rapidly changing. This is the most difficult area to accurately make optical measurements, let alone extract in-water optical and physical properties from remotely sensed data. Optical properties of the littoral zone are governed by the surrounding drainage basin, bottom characteristics, bottom resuspension based on the energetic nature of the zone, vertical and horizontal flux of nutrients, etc. Therefore, any one

littoral zone may have completely different optical properties from another thus potentially requiring regional specific remote sensing algorithm. Higher uncertainties will be found in these complex littoral waters because of the bio-optical composition (suspended material, algae and dissolved material that do not co-vary), vertical and horizontal inhomogeneities, bottom reflectance, instrument shadowing, optical extrapolation to just beneath the surface, increased atmospheric absorbing aerosols and bidirectional reflectance distribution variabilities. Because of this complexity, a specific program is required that collects optical data in littoral regions, compares these results to remote sensed data and develops improved models to spatially and temporally predict optical distributions. The uncertainty of *in situ* measurements and remote sensing data must be known, so that this information can be used in an additive or multiplicative manner to derive the total uncertainties of derived products and thus reliability indices for tactical decision aids (TDA's), which then can be used for end-user evaluations.